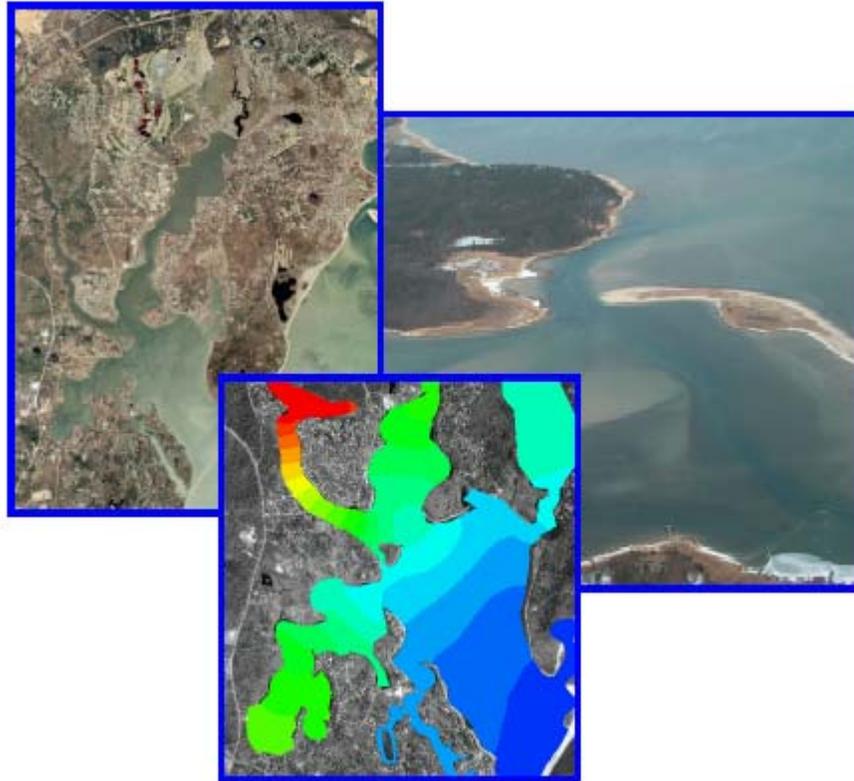


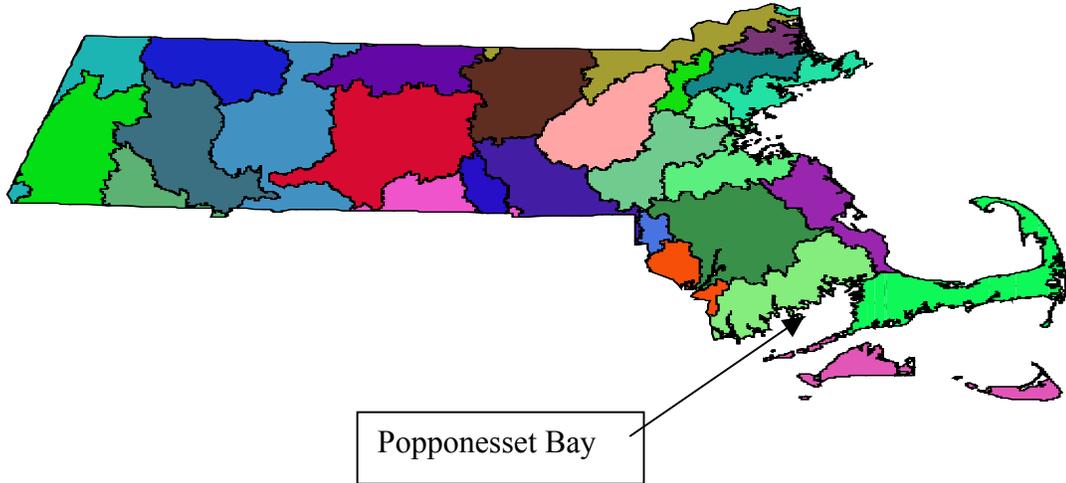
FINAL
Popponesset Bay
Total Maximum Daily Loads
For Total Nitrogen
(Report # 96-TMDL-4
Control #217.0)



COMMONWEALTH OF MASSACHUSETTS
EXECUTIVE OFFICE OF ENVIRONMENTAL AFFAIRS
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December 5, 2006

**Popponesset Bay
Total Maximum Daily Loads
For Total Nitrogen**



Key Feature: Total Nitrogen TMDL for Popponesset Bay
Location: EPA Region 1
Land Type: New England Coastal
303d Listing:

Mashpee River	MA96-24_2002	0.08 sq mi	Nutrients & Pathogens
Shoestring Bay	MA96-08_2002	0.31 sq mi	Nutrients & Pathogens
Popponesset Bay	MA96-40_2002	0.67 sq mi	Nutrients

Data Sources: University of Massachusetts – Dartmouth/School for Marine Science and Technology; US Geological Survey; Applied Coastal Research and Engineering, Inc.; Cape Cod Commission, Town of Mashpee, Town of Barnstable

Data Mechanism: Massachusetts Surface Water Quality Standards, Ambient Data, and Linked Watershed Model

Monitoring Plan: Towns of Mashpee and Barnstable monitoring program (possible assistance from SMAST)

Control Measures: Sewering, Storm Water Management, Attenuation by Impoundments and Wetlands, Fertilizer Use By-laws

EXECUTIVE SUMMARY

Problem Statement

Excessive nitrogen (N) originating primarily from on-site wastewater disposal (both conventional septic systems and innovative/alternative systems) has led to significant decreases in the environmental quality of coastal rivers, ponds, and harbors in many communities in southeastern Massachusetts. In the Towns of Mashpee and Barnstable the problems in coastal waters include:

- Loss of eelgrass beds, which are critical habitats for macroinvertebrates and fish
 - Undesirable increases in macro algae, which are much less beneficial than eelgrass
 - Periodic extreme decreases in dissolved oxygen concentrations that threaten aquatic life
 - Reductions in the diversity of benthic animal populations
 - Periodic algae blooms

With proper management of nitrogen inputs these trends can be reversed. Without proper management more severe problems might develop, including:

- Periodic fish kills
- Unpleasant odors and scum
- Benthic communities reduced to the most stress-tolerant species, or in the worst cases, near loss of the benthic animal communities

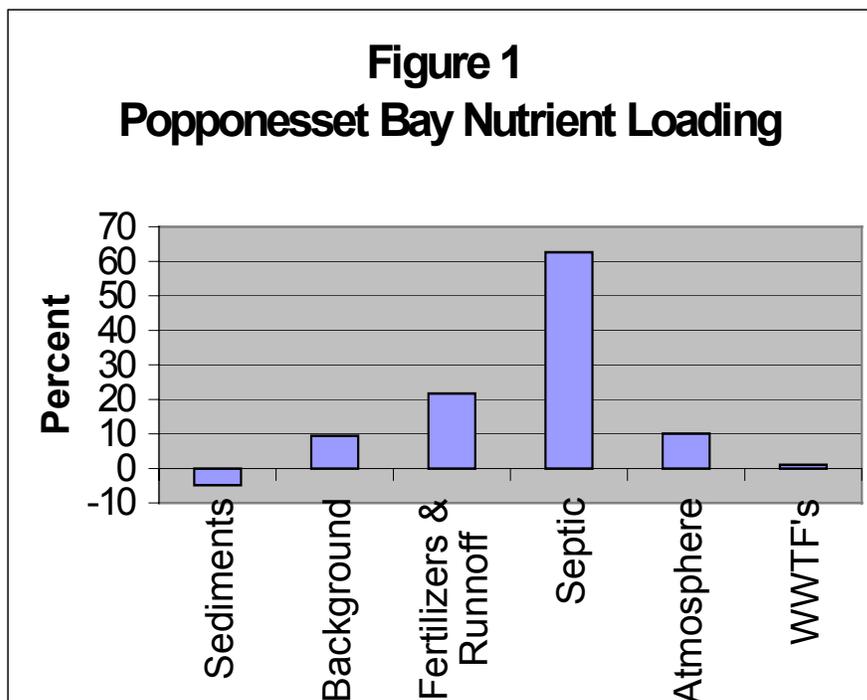
Coastal communities, including Mashpee and Barnstable, rely on clean, productive, and aesthetically pleasing marine and estuarine waters for tourism, recreational swimming, fishing, and boating, as well as for commercial fin fishing and shellfishing. Failure to reduce and control N loadings will result in complete replacement of eelgrass by macro-algae, a higher frequency of extreme decreases in dissolved oxygen concentrations and fish kills, widespread occurrence of unpleasant odors and visible scum, and a complete loss of benthic macroinvertebrates throughout most of the embayments. As a result of these environmental impacts, commercial and recreational uses of Popponesset Bay's coastal waters will be greatly reduced, and could cease altogether.

Sources of nitrogen

Nitrogen enters the waters of coastal embayments from the following sources:

- The watershed
 - On-site subsurface wastewater disposal systems
 - Natural background
 - Runoff
 - Fertilizers
- Atmospheric deposition
- Nutrient-rich bottom sediments in the embayments

Most of the present N load originates from individual subsurface wastewater disposal (septic) systems, primarily serving individual residences, as seen in the following figure.



Target Threshold Nitrogen Concentrations and Loadings

The N loadings (the quantity of nitrogen) to the Popponesset Bay sub-embayments presently range from 0.76 kg/day in Pinquicket Cove, to 39.99 kg/day in the Mashpee River. The resultant concentrations of N in the sub-embayments range from 0.422 mg/L (milligrams of nitrogen per liter) in Popponesset Bay to 0.958 mg/L in the Mashpee River.

In order to restore and protect the Popponesset Bay, N loadings, and subsequently the concentrations of N in the water, must be reduced to levels below the thresholds that cause the observed environmental impacts. The Massachusetts Estuaries Project (MEP) has determined that, for Popponesset Bay, an N concentration of 0.38 mg/L is protective. The mechanism for achieving these target N concentrations is to reduce the N loadings to the sub-embayments. The MEP has determined through mathematical modeling that the Total Maximum Daily Loads (TMDL) of N that will meet the target thresholds N loads in the 5 sub-embayments, which make up the Popponesset Bay System range from 1 to 26 kg/day. The purpose of this document is to present TMDLs for each sub-embayment and to provide guidance to the Towns on possible ways to reduce the N loadings to implement the proposed TMDLs.

Implementation

The primary goal of implementation will be lowering the concentrations of N by greatly reducing the loadings from on-site subsurface wastewater disposal systems through a variety of centralized or decentralized methods such as sewerage with nitrogen removal technology, advanced treatment of septage, upgrade/repairs of failed on-site systems, and/or installation of N-reducing on-site systems.

These strategies, plus ways to reduce N loadings from stormwater runoff and fertilizers, are explained in detail in the “MEP Embayment Restoration Guidance for Implementation Strategies”, which is available on the DEP website at (<http://www.mass.gov/dep/water/resources/restore.htm>). The appropriateness of any of the alternatives will depend on local conditions, and will have to be determined on a case-by-case basis, using an adaptive management approach.

Finally, growth within the communities of Mashpee, Barnstable, and Sandwich (part of the upper Mashpee River watershed only), which would exacerbate the problems associated with N loadings, should be guided by considerations of water quality-associated impacts.

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Introduction

Section 303(d) of the Federal Clean Water Act requires each state (1) to identify waters for which effluent limitations normally required are not stringent enough to attain water quality standards and (2) to establish Total Maximum Daily Loads (TMDLs) for such waters for the pollutants of concern. The TMDL allocation establishes the maximum loadings (of pollutants of concern), from all contributing sources, that a water body may receive and still meet and maintain its water quality standards and designated uses, including compliance with numeric and narrative standards. The TMDL development process may be described in four steps, as follows:

1. Description of water bodies and priority ranking: determination and documentation of whether or not a water body is presently meeting its water quality standards and designated uses.
2. Problem Assessment: assessment of present water quality conditions in the water body, including estimation of present loadings of pollutants of concern from both point sources (discernable, confined, and concrete sources such as pipes) and non-point sources (diffuse sources that carry pollutants to surface waters through runoff or groundwater).
3. Linking water quality and pollutant sources: determination of the loading capacity of the water body. EPA regulations define the loading capacity as the greatest amount of loading that a water body can receive without violating water quality standards. If the water body is not presently meeting its designated uses, then the loading capacity will represent a reduction relative to present loadings.
4. Total Maximum Daily Loads: specification of load allocations, based on the loading capacity determination, for non-point sources and point sources, that will ensure that the water body will not violate water quality standards.

After public comment and final approval by the EPA, the TMDL will serve as a guide for future implementation activities. The DEP will work with the Towns to develop specific implementation strategies to reduce N loadings, and will assist in developing a monitoring plan for assessing the success of the nutrient reduction strategies.

In the Popponesset Bay System, the pollutant of concern for this TMDL (based on observations of eutrophication) is the nutrient nitrogen. Nitrogen is the limiting nutrient in coastal and marine waters, which means that as its concentration is increased, so is the amount of plant matter. This leads to nuisance populations of macro-algae and increased concentrations of phytoplankton and epiphyton which impair eelgrass beds and imperil the healthy ecology of the affected water bodies.

The TMDLs for total N for the five coastal sub-embayments within the Popponesset Bay System are based primarily on data collected, compiled, and analyzed by University of Massachusetts Dartmouth's School of Marine Science and Technology (SMAST), the Towns of Mashpee and Barnstable, the Cape Cod Commission, and others, as part of the Massachusetts Estuaries Program (MEP). The data was collected over a study period from 1997 to 2003. This study period will be referred to as the "Present Conditions" in the TMDL since it is the most recent data available. The accompanying MEP Technical Report presents the results of the analyses of these five coastal sub-embayments using the MEP Linked Watershed-Embayment Nitrogen Management Model (Linked Model). The analyses were performed to assist the Towns with decisions on current and future wastewater planning, wetland restoration, anadromous fish runs, shellfisheries, open-space, and harbor maintenance programs. A critical element of this approach is the assessments of water quality monitoring data (particularly nitrogen, the limiting nutrient), historical changes in eelgrass

distribution, time-series water column oxygen measurements, and benthic community structure studies that were conducted on each sub-embayment. These assessments served as the basis for generating N loading thresholds for use as goals for watershed N management. The TMDLs are based on the site-specific thresholds generated for each sub-embayment. Thus, the MEP offers a science-based management approach to support the wastewater management planning and decision-making process in the Towns of Mashpee, Barnstable, and Sandwich.

Description of Water Bodies and Priority Ranking

The Popponeset Bay System in Mashpee and Barnstable Massachusetts, at the southwestern edge of Cape Cod, faces Nantucket Sound to the south, and consists of a number of small sub-embayments of varying size and hydraulic complexity, characterized by limited rates of flushing, shallow depths and heavily developed watersheds. These sub-embayments constitute important components of the Towns' natural and cultural resources. The nature of enclosed sub-embayments in populous regions brings two opposing elements to bear: 1) as protected marine shoreline they are popular regions for boating, recreation, and land development and 2) as enclosed bodies of water, they may not be readily flushed of the pollutants that they receive due to the proximity and density of development near and along their shores. In particular, the sub-embayments within the Popponeset Bay System are at risk of further eutrophication from high nutrient loads in the groundwater and runoff from their watersheds. Because of excessive nutrients, 3 sub-embayments are already listed as waters requiring TMDLs (Category 5) in the MA 2002 Integrated List of Waters, as summarized in Table 1A. This report will provide target loads and concentrations necessary to meet water quality standards. Where present conditions already achieve standards this report will serve to provide a concentration and load necessary to protect the resource into the future.

Table 1A. Popponeset Bay sub-embayments in Category 5 of the Massachusetts 2002 Integrated List¹

NAME	SEGMENT ID	DESCRIPTION	SIZE	Pollutant Listed
Popponeset Bay System				
Mashpee River	MA96-24_2002	Quinaquisset Avenue to mouth at Shoestring Bay (formerly to mouth of Popponeset Bay), Mashpee	0.08 sq mi	Nutrients & Pathogens
Shoestring Bay	MA96-08_2002	Quinaquisset Avenue to Popponeset Bay (line from Ryefield Point, Barnstable to Punkhorn Point, Mashpee, including Gooseberry Island), Barnstable/Mashpee	0.31 sq mi	Nutrients & Pathogens
Popponeset Bay	MA96-40_2002	From line connecting Ryefield Point, Barnstable to Punkhorn Point, Mashpee, to inlet of Nantucket Sound (including Ockway Bay and Pinquickset Cove), Mashpee/Barnstable	0.67 sq mi	Nutrients

¹ These segments are also classified as Category 5 on the Draft 2004 Integrated List.

A complete description of all 5 sub-embayments is presented in Chapters I and IV of the MEP Technical Report from which the majority of the following information is drawn. TMDLs were calculated for all 5 sub-embayments listed below. Analytical and modeling efforts were conducted by grouping these 5 sub-embayments, into a single embayment system, which flows into Nantucket Sound to the south.

- Popponeset Bay System:
 1. Mashpee River
 2. Shoestring Bay
 3. Ockway Bay
 4. Pinquickset Cove
 5. Popponeset Bay

The sub-embayments addressed by this document are determined to be high priorities based on 3 significant factors: (1) the initiative that these Towns have taken to assess the conditions of the entire Popponeset embayment system, (2) the commitment made by these Towns to restoring and preserving the sub-embayments, and (3) the extent of eutrophication in the sub-embayments. In particular, these sub-embayments are at risk of further degradation from increased N loads entering through groundwater and surface water from their increasingly developed watersheds. In both marine and freshwater systems, an excess of nutrients results in degraded water quality, adverse impacts to ecosystems, and limits on the use of water resources. The general conditions related to the major indicators of habitat impairment, due to excess nutrient loadings, are tabulated in Table 1B. Observations are summarized in the Problem Assessment section below, and detailed in Chapter VII, Assessment of Embayment Nutrient Related Ecological Health, of the MEP Technical Report.

Table 1B. General summary of conditions related to the major indicators of habitat impairment observed in Popponeset Bay System.

Popponeset Bay System Sub-embayments	Eel Grass Loss ¹	Dissolved Oxygen	Chlorophyll <i>a</i> ²	Benthic Fauna ³
Mashpee River	100%	<6 mg/l (51% of time) <4 mg/L (27% of time) SD	>10ug/l (up to 60% of time) >20ug/L (up to 19% of time) SD	SI
Shoestring Bay	100%	<6 mg/l (48% of time) <4 mg/L (9% of time) SD	>10ug/l (up to 60% of time) >20ug/L (up to 23% of time) SD	SI
Ockway Bay	NS	<6 mg/l (47% of time) <4mg/L (19% of time) SD	>10ug/L (up to 29% of time) >20ug/L (up to 4% of time) SD	SI
Pinquickset Cove	No data	No mooring data	>10ug/L (up to 42% of time) >20ug/L (up to 28% of time) SD	No data
Popponeset Bay	100%	<6mg/l (60% of time) <4mg/l (24% of time) GF	>10ug/L (up to 21% of time) >20ug/L (up to 12% of time) SD	SI

¹ There is presently no eelgrass within the Popponeset Bay System, although it was documented in a 1951 survey

² Algal blooms are consistent with chlorophyll *a* levels above 20 ug/L

³ Based on observations of the type of species, number of species, and number of individuals

GF – Good to Fair – little or no change from normal conditions *

MI – Moderately Impaired – slight to reasonable change from normal conditions *

SI – Significantly Impaired- considerably and appreciably changed from normal conditions *

SD – Severe Degraded – critically or harshly changed from normal conditions *

NS - Non-supportive habitat, no eelgrass was present in 1951 Survey data.

* - these terms are more fully described in MEP report “Site-Specific Nitrogen Thresholds for Southeastern Massachusetts Embayments: Critical Indicators”

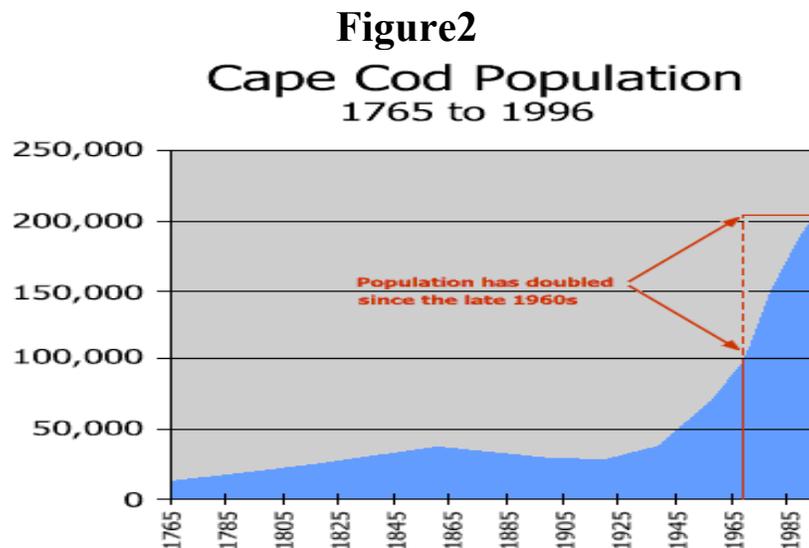
December 22, 2003 (<http://www.mass.gov/dep/smerp/files/nitroest.pdf>)

Problem Assessment

The watersheds of Popponesset Bay's estuaries have all had rapid and extensive development of single-family homes and the conversion of seasonal into full time residences. This is reflected in a substantial transformation of land from forest to suburban use between the years 1951 to 2000. Water quality problems associated with this development result primarily from on-site wastewater treatment systems, and to a lesser extent, from runoff - including fertilizers - from these developed areas.

On-site subsurface wastewater disposal system effluents discharge to the ground, enter the groundwater system and eventually enter the surface water bodies. In the sandy soils of Cape Cod, effluent that has entered the groundwater travel towards the coastal waters at an average rate of one foot per day. The nutrient load to the groundwater system is directly related to the number of subsurface wastewater disposal systems, which in turn are related to the population. The population of Mashpee and Barnstable, as with all of Cape Cod, has increased markedly since 1950. In addition, summertime residents and visitors swell the population of the entire Cape by about 300% according to the Cape Cod Commission (<http://www.capecodcommission.org/data/trends98.htm#population>).

The increase in year round residents is illustrated in the following graph:



Sources:

- 1) Cape Cod Commission. (1997). [Cape Trends: Cape Cod demographic and economic trends 1997 \[online\]](#).
- 2) Wilkie, Richard W. and Jack Tager, [eds.]. 1991. Historical Atlas of Massachusetts. University of Massachusetts Press. Amherst, MA. 152 pp.

Prior to the 1950's there were few homes and many of those were seasonal. During these times water quality was not a problem and eel grass beds were plentiful. Dramatic declines in water quality, and the quality of the estuarine habitats, throughout Cape Cod, have paralleled its population growth since these times. The problems in these particular sub-embayments generally include periodic decreases of dissolved oxygen, decreased diversity of benthic animals, and periodic algal blooms. Eelgrass beds, which are critical habitats for macroinvertebrates and fish, have completely disappeared from these waters. Furthermore, the eelgrass was replaced by macro algae, which are

undesirable, because they do not provide high quality habitat for fish and invertebrates. In the most severe cases habitat degradation could lead to periodic fish kills, unpleasant odors and scums, and near loss of the benthic community and/or presence of only the most stress-tolerant species of benthic animals.

Coastal communities, including Mashpee and Barnstable, rely on clean, productive, and aesthetically pleasing marine and estuarine waters for tourism, recreational swimming, fishing, and boating, as well as commercial fin fishing and shellfishing. The continued degradation of these coastal sub-embayments, as described above, will significantly reduce the recreational and commercial value and use of these important environmental resources.

Habitat and water quality assessments were conducted on each sub-embayment based upon water quality data, historical changes in eelgrass distribution, time-series water column oxygen measurements, and benthic community structure. The five sub-embayment systems in this study display a range of habitat quality. In general, the habitat quality of the Popponesset Bay System is highest near the tidal inlet on Nantucket Sound and poorest in the inland-most tidal reaches. This is indicated by gradients of the various indicators. Nitrogen concentrations are highest inland and lowest near the mouths. A high resolution aerial photography survey from 1951 indicates there were significant eelgrass beds in the central basin as well as eelgrass beds within the upper basin near the mouth of Shoestring Bay. Subsequent field surveys in 1995 and 2001 have both shown the complete loss of all eelgrass beds throughout the Popponesset Bay System. This makes the presence or loss of eelgrass a difficult parameter to use in evaluating water quality within the sub-embayments. Infaunal study results indicate a system capable of supporting diverse healthy communities in the region nearest the tidal inlet, with most of the system having infaunal habitat that is significantly impaired under present N loading conditions. Currently the central basin of Popponesset Bay supports relatively healthy habitat conditions of consistently high bottom water dissolved oxygen and modest phytoplankton blooms during the summer months. The other sub-embayments within the system have moderate to high levels of nitrogen-related impairment. Shoestring Bay shows both periodic oxygen declines and significant phytoplankton blooms, while Ockway Bay has similar oxygen declines, but apparently less phytoplankton biomass. Upper Mashpee River dissolved oxygen measurements showed <3 mg/L during 20% of the days tested. Chlorophyll *a* concentrations are the highest in the inland reaches. Shoestring Bay and Mashpee River both have phytoplankton blooms, which are common and large (chlorophyll *a* concentrations >20 ug/L). Overall the Popponesset Bay central basin has relatively high water quality, Popponesset Bay upper basin and confluence with Shoestring Bay and Ockway Bay is significantly impaired, and the Mashpee River sub-embayment is significantly impaired.

Pollutant of Concern, Sources, and Controllability

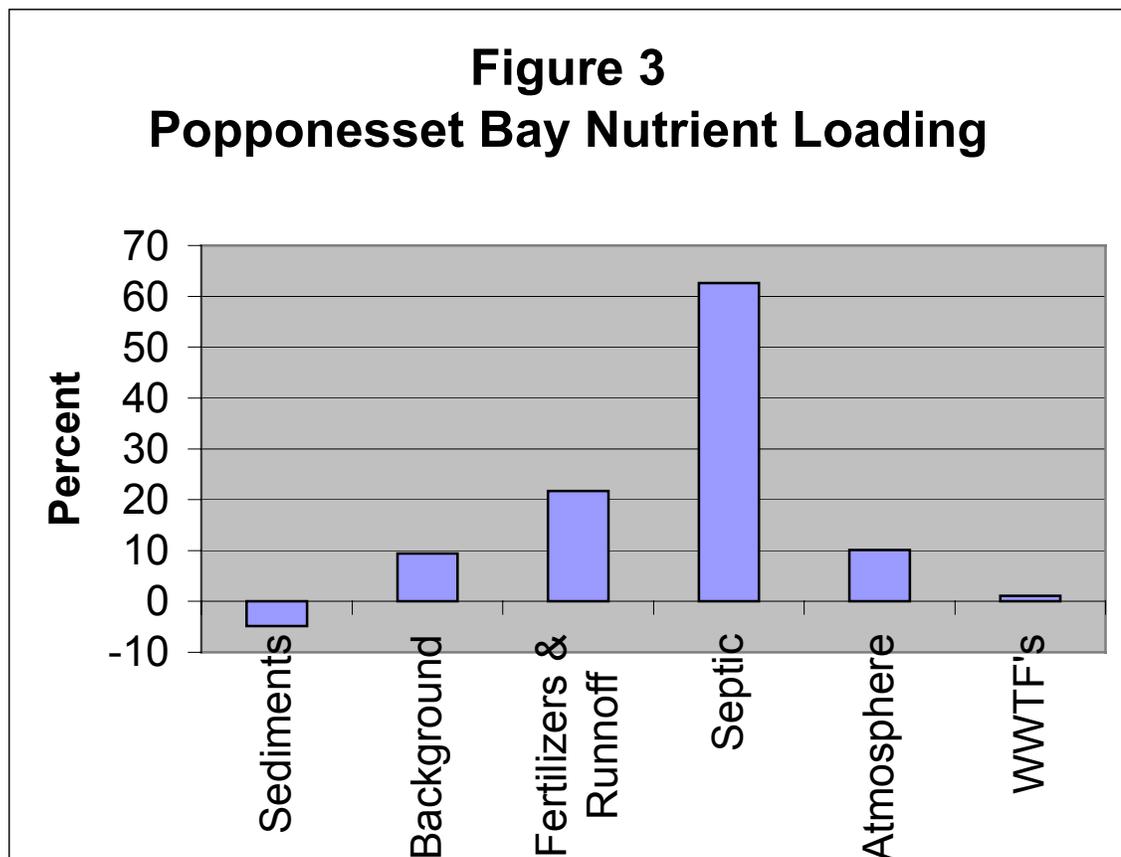
In the coastal embayments of the Towns of Mashpee and Barnstable, as in most marine and coastal waters, the limiting nutrient is nitrogen. Nitrogen concentrations above natural levels contribute to undesirable conditions, including the severe impacts described above, through the promotion of excessive growth of plants and algae, including nuisance vegetation.

Each of the embayments covered in this TMDL has had extensive data collected and analyzed through the Massachusetts Estuaries Program (MEP) and with the cooperation and assistance from the Town of Mashpee, the Town of Barnstable, the USGS, and the Cape Cod Commission. Data collection included both water quality and hydrodynamics as described in Chapters I, IV, V, and VII of the MEP Technical Report.

These investigations revealed that loadings of nutrients, especially N, are much larger than they would be under natural conditions, and as a result the water quality has deteriorated. A principal indicator of decline in water quality is the disappearance of eelgrass from its entire natural habitat in these sub-embayments. This is a result of nutrient loads causing excessive growth of algae in the water (phytoplankton) and algae growing on eel grass (epiphyton), both of which result in the loss of eelgrass through the reduction of available light levels.

As is illustrated by Figure 3, most of the N affecting Popponesset Bay’s sub-embayments originates from on-site subsurface wastewater disposal systems, with considerably less N originating from natural background sources, runoff, fertilizers, waste water treatment facilities, and atmospheric deposition. Although this figure shows that overall the sediments are a N sink, examination of individual sub-embayments indicates that some of them have sediments that provide significant sources of N (Table 3).

Percent contribution of various sources and sinks of nitrogen in Popponesset Bay’s embayments



The level of “controllability” of each source, however, varies widely:

Atmospheric nitrogen cannot be adequately controlled locally – it is only through region and nation-wide air pollution control initiatives that reductions are feasible;

Sediment nitrogen control by such measures as dredging is not feasible on a large scale. However, the concentrations of N in sediments, and thus the loadings from the sediments, will decline over time

if sources in the watershed are removed, or reduced to the target levels discussed later in this document. Increased dissolved oxygen will help keep nitrogen from fluxing;

Fertilizer – related nitrogen loadings can be reduced through bylaws and public education;

Stormwater sources of N can be controlled by best management practices (BMPs), bylaws and stormwater infrastructure improvements;

Septic system sources of nitrogen are the largest controllable sources. These can be controlled by a variety of case-specific methods including: sewerage and treatment at centralized or decentralized locations, upgrading/repairing failed systems, transporting and treating septage at treatment facilities with N removal technology either in or out of the watershed, or installing nitrogen-reducing on-site wastewater treatment systems.

Natural Background is the background load as if the entire watershed was still forested and contains no anthropogenic sources. It cannot be controlled locally.

WWTFs effluent nitrogen can be reduced by advanced treatment processes that include denitrification.

Landfill leachate nitrogen is included in the land use loading source, can best be controlled by collecting and treating the leachate, but can also be controlled by capping the landfill to prevent percolation of rainwater through the landfill (and thus capturing and transporting contaminants into the groundwater). The Mashpee landfill capping was completed in 1998.

Cost/benefit analyses will have to be conducted on all of the possible N loading reduction methodologies in order to select the optimal control strategies, priorities, and schedules.

Description of the Applicable Water Quality Standards

Water quality standards of particular interest to the issues of cultural eutrophication are dissolved oxygen, nutrients, aesthetics, excess plant biomass, and nuisance vegetation. The Massachusetts water quality standards (314 CMR 4.0) contain numeric criteria for dissolved oxygen, but have only narrative standards that relate to the other variables, as described below:

314 CMR 4.05(5)(a) states “Aesthetics – All surface waters shall be free from pollutants in concentrations that settle to form objectionable deposits; float as debris, scum, or other matter to form nuisances, produce objectionable odor, color, taste, or turbidity, or produce undesirable or nuisance species of aquatic life.”

314 CMR 4.05(5)(c) states, “Nutrients – Shall not exceed the site-specific limits necessary to control accelerated or cultural eutrophication”.

314 CMR 4.05(b) 1:

(a) Class SA

1. Dissolved Oxygen -

- a. Shall not be less than 6.0 mg/l unless background conditions are lower;
- b. natural seasonal and daily variations above this level shall be maintained; levels shall not be lowered below 75% of saturation due to a discharge; and

c. site-specific criteria may apply where background conditions are lower than specified levels or to the bottom stratified layer where the Department determines that designated uses are not impaired.

(b) Class SB

1. Dissolved Oxygen -

- a. Shall not be less than 5.0 mg/L unless background conditions are lower;
- b. natural seasonal and daily variations above this level shall be maintained; levels shall not be lowered below 60% of saturation due to a discharge; and
- c. site-specific criteria may apply where back-ground conditions are lower than specified levels or to the bottom stratified layer where the Department determines that designated uses are not impaired.

Thus, the assessment of eutrophication is based on site specific information within a general framework that emphasizes impairment of uses and preservation of a balanced indigenous flora and fauna. This approach is recommended by the US Environmental Protection Agency in their draft Nutrient Criteria Technical Guidance Manual for Estuarine and Coastal Marine Waters (EPA-822-B-01-003, Oct 2001). The Guidance Manual notes that lakes, reservoirs, streams, and rivers may be subdivided by classes, allowing reference conditions for each class and facilitating cost-effective criteria development for nutrient management. However, individual estuarine and coastal marine waters have unique characteristics, and development of individual water body criteria is typically required.

It is this framework, coupled with an extensive outreach effort that the Department, with the technical support of SMAST, is employing to develop nutrient TMDLs for coastal waters.

Methodology - Linking Water Quality and Pollutant Sources

Extensive data collection and analyses have been described in detail in the MEP Technical Report. Those data were used by SMAST to assess the loading capacity of each embayment. Physical (Chapter V), chemical and biological (Chapters IV, VII, and VIII) data were collected and evaluated. The primary water quality objective was represented by conditions that:

- 1) restore the natural distribution of eelgrass because it provides valuable habitat for shellfish and finfish
- 2) prevent algal blooms
- 3) protect benthic communities from impairment or loss
- 4) maintain dissolved oxygen concentrations that are protective of the estuarine communities.

The details of the data collection, modeling and evaluation are presented and discussed in Chapters IV, V, VI, VII and VIII of the MEP Technical Report. The main aspects of the data evaluation and modeling approach are summarized below, taken from pages 4 through 7 of that report.

The core of the Massachusetts Estuaries Project analytical method is the Linked Watershed-Embayment Management Modeling Approach. It fully links watershed inputs with embayment circulation and N characteristics, and is characterized as follows:

- requires site specific measurements within the watershed and each sub-embayment;

- uses realistic “best-estimates” of N loads from each land-use (as opposed to loads with built-in “safety factors” like Title 5 design loads);
- spatially distributes the watershed N loading to the embayment;
- accounts for N attenuation during transport to the embayment;
- includes a 2D or 3D embayment circulation model depending on embayment structure;
- accounts for basin structure, tidal variations, and dispersion within the embayment;
- includes N regenerated within the embayment;
- is validated by both independent hydrodynamic, N concentration, and ecological data;
- is calibrated and validated with field data prior to generation of “what if” scenarios.

The Linked Model has been applied previously to watershed N management in 15 embayments throughout Southeastern Massachusetts. In these applications it became clear that the model can be calibrated and validated, and has use as a management tool for evaluating watershed N management options.

The Linked Model, when properly calibrated and validated for a given embayment, becomes a N management planning tool as described in the model overview below. The model can assess solutions for the protection or restoration of nutrient-related water quality and allows testing of management scenarios to support cost/benefit evaluations. In addition, once a model is fully functional it can be refined for changes in land-use or embayment characteristics at minimal cost. In addition, since the Linked Model uses a holistic approach that incorporates the entire watershed, embayment and tidal source waters, it can be used to evaluate all projects as they relate directly or indirectly to water quality conditions within its geographic boundaries.

The Linked Model provides a quantitative approach for determining an embayment's: (1) N sensitivity, (2) N threshold loading levels (TMDL) and (3) response to changes in loading rate. The approach is fully field validated and unlike many approaches, accounts for nutrient sources, attenuation, and recycling and variations in tidal hydrodynamics (Figure I-2 of the MEP Technical Report). This methodology integrates a variety of field data and models, specifically:

- Monitoring - multi-year embayment nutrient sampling
- Hydrodynamics -
 - embayment bathymetry (depth contours throughout the embayment)
 - site specific tidal record (timing and height of tides)
 - water velocity records (in complex systems only)
 - hydrodynamic model

- Watershed Nitrogen Loading
 - watershed delineation
 - stream flow and N load
 - land-use analysis (GIS)
 - watershed N model

- Embayment TMDL - Synthesis
 - linked Watershed-Embayment Nitrogen Model
 - salinity surveys (for linked model validation)
 - rate of N recycling within embayment
 - dissolved oxygen record
 - Macrophyte survey
 - Infaunal survey (in complex systems)

Application of the Linked Watershed-Embayment Model

The approach developed by the MEP for applying the linked model to specific sub-embayments, for the purpose of developing target N loading rates, includes:

- 1) selecting one or two sub-embayments within the embayment system, located close to the inland-most reach or reaches, which typically has the poorest water quality within the system. These are called “sentinel” sub-embayments;

- 2) using site-specific information and a minimum of 3 years of sub-embayment-specific data to select target/threshold N concentrations for each sub-embayment. This is done by refining the draft threshold N concentrations that were developed as the initial step of the MEP process. The target concentrations that were selected generally occur in higher quality waters near the mouth of the embayment system;

- 3) running the calibrated water quality model using different watershed N loading rates, to determine the loading rate, which will achieve the target N concentration within the sentinel sub-embayment. Differences between the modeled N load required to achieve the target N concentration, and the present watershed N load, represent N management goals for restoration and protection of the embayment system as a whole.

Previous sampling and data analyses, and the modeling activities described above, resulted in four major outputs that were critical to the development of the TMDLs. Two outputs are related to N **concentration**:

- the present N concentrations in the sub-embayments
- site-specific target (threshold) concentrations

and, two outputs are related to N **loadings**:

- the present N loads to the sub-embayments
- load reductions necessary to meet the site specific target N concentrations

A brief overview of each of the outputs follows:

Nitrogen concentrations in the sub-embayments

a) Observed “present” conditions:

Table 2 presents the range of average concentrations of N measured in the sub-embayments from 1997 through 2003. Concentrations of N are the highest in the Mashpee River (0.958 mg/L). Nitrogen in the other sub-embayments ranges in concentration from 0.456 to 0.690 mg/L, resulting in overall ecological habitat quality ranging from moderately healthy to severely degraded. The individual yearly means and standard deviations of the averages are presented in Tables A-1 of Appendix A.

b) Modeled site-specific target threshold nitrogen concentrations:

A major component of TMDL development is the determination of the maximum concentrations of N (based on field data) that can occur without causing unacceptable impacts to the aquatic environment. Prior to conducting the analytical and modeling activities described above, SMAST selected appropriate nutrient-related environmental indicators and tested the qualitative and quantitative relationship between those indicators and N concentrations. The Linked Model was then used to determine site-specific threshold N concentrations by using the specific physical, chemical and biological characteristics of each sub-embayment.

Table 2. Observed present nitrogen concentrations and calculated target threshold nitrogen concentrations derived for the Popponeset Bay Sub-embayments

Embayment System And Sub-embayments	Range of Average Observed System Nitrogen Concentration ¹ (mg/L)	System Threshold Nitrogen Concentration (mg/L)
Popponeset Bay		0.38
Mashpee River	0.958-0.627 ²	
Shoestring Bay	0.690-0.520 ²	
Ockway Bay	0.677-0.536 ²	
Pinquickset Cove	0.527	
Popponeset Bay	0.485-0.422 ²	

¹ calculated as the average of the separate yearly means of 1997-2003 data. Individual yearly means and standard deviations of the average are presented in Tables A-1 Appendix A

²listed as a range since it was sampled as several segments(see Table A-1 Appendix A)

As shown in Table 2, the site-specific target (threshold) N concentration is 0.38 mg/L for all of the Popponeset Bay embayment.

The findings of the analytical and modeling investigations for this embayment system are discussed and explained below:

The threshold N level for an embayment represents the average water column concentration of N that will support the high habitat quality being sought. The water column N level is ultimately controlled by the integration of the watershed N load, the N concentration in the inflowing tidal waters (boundary condition) and dilution and flushing via tidal flows. The water column N concentration is modified by the extent of sediment uptake and/or regeneration and by direct atmospheric deposition.

The threshold N levels for the embayment in this study were developed to restore or maintain SA

waters or high habitat quality. In the embayment, high habitat quality was defined as supportive of eelgrass and diverse benthic animal communities. Dissolved oxygen and chlorophyll *a* were also considered in the assessment.

Watershed N loads (Tables ES-1 and ES-2 of the MEP Technical Report) to the Popponeset Bay System from the Towns of Mashpee and Barnstable were comprised primarily of septic system N loading. Analysis of the overall septic system load to the 5 sub-embayments in the Popponeset Bay System indicate that 70% of the N load is from this source.

The threshold N level for the Popponeset Bay System was determined as follows:

- The target N concentration for restoration of eelgrass in this system was determined to be 0.38 mg/L Total Nitrogen (TN). The value stems from (1) the analysis of Stage Harbor, Chatham which also exchanges tidal water with Nantucket Sound and for which a target has already been set), (2) analysis of N levels within the vestigial eelgrass bed in adjacent Waquoit Bay, near the inlet (measured TN of 0.395 mg/L, this value is tidally averaged to <0.38 mg/L), and (3) a similar analysis in West Falmouth Harbor. Threshold values relating to eelgrass restoration were based upon these other Cape Cod systems with similar N dynamics, since there are presently no remaining eelgrass beds in the Popponeset Bay System (or even adjacent Three Bays).
- The sentinel station was located within the upper region of the central basin to Popponeset Bay at the mouth of Shoestring Bay, at the uppermost eelgrass bed detected in the 1951 data. Under present loading conditions the sentinel station supports a measured N level at mid-ebb tide of 0.581 mg/L TN and a tidally corrected average concentration of 0.451 mg/L TN. This location was selected as a sentinel station because: (1) it was the upper extent of the eelgrass coverage in 1951, (2) restoration of N conditions supportive of eelgrass at this location will necessarily result in even higher quality conditions throughout the whole of the central basin, and (3) restoration of N concentrations at this site should result in conditions similar to 1951 within Shoestring and Ockway Bays. Shoestring Bay and Ockway Bay should then be supportive of high quality habitat for benthic infaunal communities. Based upon current conditions, the infaunal analysis (Chapter VII, MEP Technical Report) coupled with the N data (measured and modeled), indicated that N levels on the order of 0.4 to 0.5 mg/L TN are supportive of high quality infauna habitat within the Popponeset Bay System.
- Based upon sequential reductions in watershed N loading in the analysis described in the Section VIII-3 of the MEP Technical Report, the sentinel station is projected to achieve an average TN level of 0.371 mg/L, the mouth of Ockway Bay 0.376 mg/L TN, and the whole of the Popponeset Bay basin <0.331 mg/L TN.

The data suggest that there is likely a range of total N, which can support a healthy infaunal community within this system. Since Shoestring and Ockway Bays did not support eelgrass in the 1951 data, evaluation was based upon benthic animal habitat.

- The results of the Linked Watershed-Embayment modeling indicated that when the N threshold level is attained at the sentinel station (Section VIII-3 of the MEP Technical report), TN levels in Shoestring and Ockway Bays will be consistent with high quality infauna habitat: upper and lower Shoestring Bay, 0.522 and 0.412 mg/L TN respectively; upper Ockway Bay, 0.421 mg/L TN; and mid and lower Mashpee River, 0.525 and 0.422 mg/L TN.

- The model shows that achieving the N target at the sentinel station will be restorative of eelgrass habitat throughout the Popponeset Bay central basin and restorative of infaunal habitat throughout Shoestring and Ockway Bays and the lower portion of the Mashpee River.
- It is important to note that the analysis of future N loading to the Popponeset Bay System focuses upon additional shifts in land-use from forest/grasslands to residential and commercial development. However, the analysis (as described in Chapter VI of the MEP Technical Report) indicates that significant increases in N loading can occur under present land-uses, due to shifts in occupancy, shifts from seasonal to year-round usage and increasing use of fertilizers (presently less than half of the parcels use lawn fertilizers). Therefore, watershed-estuarine N management must include management approaches to prevent increased N loading from both shifts in land-uses (new sources) and from loading increases of current land-uses. The overwhelming conclusion of the analysis of the Popponeset Bay System is that restoration will necessitate a reduction in the present (2003) N inputs and management options to negate additional future N inputs.

Nitrogen loadings to the sub-embayments

a) Present loading rates:

In the Popponeset Bay System overall, the highest N loading from controllable sources is from septic systems, which is also the highest N loading source in each sub-embayment. On-site septic system loadings range from 0.58 kg/day to as high as 26.46 kg/day. Nitrogen loading from the nutrient-rich sediments (referred to as benthic flux) is significant in the Mashpee River sub-embayment. As discussed previously, however, the direct control of N from sediments is not considered feasible. However, the magnitude of the benthic contribution is related to the watershed load. Therefore, reducing the incoming load should reduce the benthic flux over time. The total N loading from all sources ranges from 0.84 kg/day in Pinquicket Cove to 52.71 kg/day in the Mashpee River. A further breakdown of N loading, by source, is presented in Table 3. The data on which Table 3 is based can be found in Table ES-1 of the MEP Technical Report.

Table 3. Nitrogen loadings to the Popponeset Bay sub-embayments from within the watersheds (natural background, land use-related runoff, and septic systems), from WWTFs from the atmosphere, and from nutrient-rich sediments within the embayments.

Popponeset System Sub-embayments	Natural Background Watershed Load (kg/day) ¹	Present Land Use Load (kg/day) ²	Present Septic System Load (kg/day)	Present WWTF Load (kg/day)	Present Atmospheric Deposition (kg/day)	Present Benthic Flux ³ (kg/day)	Total nitrogen load from all sources (kg/day)
Mashpee River	5.86	10.38 ^a	23.62	0.15	0.66	15.34	56.01
Shoestring Bay	2.05	7.77	23.00	0.47	2.23	-11.85	23.67
Ockway Bay	0.24	0.76	2.39	0.00	1.09	1.78	6.26
Pinquicket Cove	0.11	0.19	0.58	0.00	0.29	-0.33	0.84
Popponeset Bay	0.18	1.19	5.56	0.00	4.01	-5.68	5.26

¹ assumes entire watershed is forested (i.e., no anthropogenic sources)

² composed of fertilizer and runoff only

³ nitrogen loading from the sediments

^a includes residual plume from the capped Mashpee Landfill (0.39 kg/day)

b) Nitrogen loads necessary for meeting the site-specific target nitrogen concentrations.

As previously indicated, the present N loadings to the Popponesset Bay sub-embayments must be reduced in order to restore conditions and to avoid further nutrient-related adverse environmental impacts. The critical final step in the development of the TMDL is modeling and analysis to determine the loadings required to achieve the target N concentrations.

Table 4 lists the present controllable N loadings, target thresholds, and reductions necessary to achieve target concentrations (which will be described more fully in the following section). It should be noted once again that the goal of this TMDL is to achieve the target N concentration in the designated sentinel system. The loadings presented in Table 4 represent one, but not the only, loading reduction scenario that can meet the TMDL goal. In this scenario, the percentage reductions to meet threshold concentrations range from 1 % at Pinguickset Cove up to 76% at Ockway Bay. Table VIII-1 of the MEP Technical Report (and reproduced in Appendix B of this document) summarizes the present loadings from on-site subsurface wastewater disposal systems, and the reduced loads that would be necessary to achieve the threshold N concentrations in the Popponesset Bay System if on-site subsurface wastewater disposal system loads alone were targeted.

Table 4. Present Controllable Watershed nitrogen loading rates, calculated loading rates that are necessary to achieve target threshold nitrogen concentrations, and the percent reductions of the existing loads necessary to achieve the target threshold loadings.

Popponesset Bay System Sub-embayments	Present controllable watershed load ¹ (kg/day)	Target Threshold Watershed Load ² (kg/day)	Percent watershed load reductions needed to achieve threshold loads
Mashpee River	34.15	16.17	52.7
Shoestring Bay	31.24	19.72	36.9
Ockway Bay	3.15	0.76	75.9
Pinguickset Cove	0.77	0.76	1.3
Popponesset Bay	6.75	2.77	59.0

¹ Composed of combined fertilizer, runoff, WWTP effluent, and septic system loadings

² Target threshold watershed load is the load from the watershed needed to meet the embayment threshold N concentration of 0.38 mg/L identified in Table 2 above.

Total Maximum Daily Loads

As described in EPA guidance, a total maximum daily load (TMDL) identifies the loading capacity of a water body for a particular pollutant. EPA regulations define loading capacity as the greatest amount of loading that a water body can receive without violating water quality standards. The TMDLs are established to protect and/or restore the estuarine ecosystem, including eelgrass and benthic animal community structure, the leading indicator of ecological health, thus meeting water quality goals for aquatic life support. Because there are no “numerical” water quality standards for N, the TMDLs for the Popponesset Bay sub-embayments are aimed at determining the loads that would correspond to sub-embayment-specific N concentrations determined to be protective of the water quality and ecosystems.

The effort includes detailed analyses and mathematical modeling of land use, nutrient loads, water quality indicators, and hydrodynamic variables (including residence time), for each sub-embayment. The results of the mathematical model are correlated with estimates of impacts on water quality, including negative impacts on eelgrass (the primary indicator), as well as dissolved oxygen, chlorophyll, and benthic infauna. The TMDL can be defined by the equation:

$$\text{TMDL} = \text{BG} + \text{WLAs} + \text{LAs} + \text{MOS}$$

Where

TMDL = loading capacity of receiving water

BG = natural background

WLAs = portion allotted to point sources

LAs = portion allotted to (cultural) non-point sources

MOS = margin of safety

Background Loading

Natural background N loading estimates are presented in Table 3 above. Background loading was calculated on the assumption that the entire watershed is forested, with no anthropogenic sources of N.

Wasteload Allocations

Wasteload allocations identify the portion of the loading capacity allocated to existing and future point sources of wastewater. EPA interprets 40 CFR 130.2(h) to require that allocations for NPDES regulated discharges of storm water be included in the waste load component of the TMDL. On Cape Cod the vast majority of storm water percolates into the ground and aquifer and proceeds into the embayment systems through groundwater migration. The Linked Model accounts for storm water loadings and groundwater loading in one aggregate allocation as a non-point source – combining the assessments of waste water and storm water (including storm water that infiltrates into the soil and direct discharge pipes into water bodies) for the purpose of developing control strategies. Although the vast majority of storm water percolates into the ground, there are a few storm water pipes that discharge directly to water bodies that are subject to the requirements of the Phase II Storm Water NPDES Program. Therefore, any storm water discharges subject to the requirements of storm water Phase II NPDES permit must be treated as a waste load allocation. Since the majority of the nitrogen loading comes from septic systems, fertilizer and storm water that infiltrates into the groundwater, the allocation of nitrogen for any storm water pipes that discharge directly to any of the embayments is insignificant as compared to the overall groundwater load. Based on land use, the Linked Model accounts for loading for storm water, but does not differentiate storm water into a load and waste load allocation. Nonetheless, based on the fact that there are few storm water discharge pipes within NPDES Phase II communities that discharge directly to embayments or waters that are connected to the embayments, the waste load allocation for these sources is considered to be less than 0.29% (93.7 kg/year) as compared to the overall nitrogen load (31,885 kg/year) to the embayments. Looking at individual sub-embayments this load ranged from 0.09-1.59% compared to the individual nitrogen load to each sub-embayment (Appendix C). This is based on the percent of impervious surface within 200 feet of the waterbodies and the relative load from this area compared to the overall load (Table IV-5 of the MEP Technical Report). Although most stormwater infiltrates into the ground on Cape Cod, some impervious areas within approximately 200 of the shoreline may discharge stormwater via pipes directly to the waterbody. For the purposes of waste load allocation it was

assumed that all impervious surfaces within 200ft of the shoreline discharge directly to the waterbody. This load is obviously negligible when compared to other sources.

There are four wastewater treatment facilities that discharge to groundwater in the Popponesset Bay watershed, but they are not considered point sources under EPA definition. Two of these are in the Shoestring Bay sub-embayment and the other two are in the Mashpee River sub-embayment. EPA policy also requires that stormwater regulated under the NPDES program be identified and included as a wasteload allocation. As discussed, for the purpose of this TMDL, stormwater loadings are not differentiated into point and non-point sources, because most storm water discharges directly to the ground.

EPA and DEP authorized the Towns of Mashpee, Barnstable, and Sandwich for coverage under the NPDES Phase II General Permit for Stormwater Discharges from Small Municipal Separate Storm Sewer Systems (MS4s) in 2003. The watershed of the Popponesset Bay System that is in Mashpee and Sandwich are located in an area subject to the requirements of the permit, as EPA has mapped these entire areas of the watershed as regulated areas. EPA did not designate the entire watershed area in Barnstable as a regulated urbanized area. While communities need to comply with the Phase II permit only in the mapped Urbanized Areas, the Town of Barnstable has decided to extend all the stormwater permit requirements throughout the entire town, including the Popponesset Bay System watershed area.

The Phase II general permit requires the permittee to determine whether the approved TMDL is for a pollutant likely to be found in storm water discharges from the MS4. The MS4 is required to implement the storm water waste load allocation, BMP recommendations or other performance requirements of a TMDL and assess whether the waste load allocation is being met through implementation of existing stormwater control measures or if additional control measures are necessary.

Load Allocations

Load allocations identify the portion the loading capacity allocated to existing and future nonpoint sources. In the case of the Popponesset Bay System, the nonpoint source loadings are primarily from on-site subsurface wastewater disposal systems. Additional N sources include: natural background, stormwater runoff (including N from fertilizers), the four WWTF's groundwater discharges, atmospheric deposition, and nutrient-rich sediments.

Generally, stormwater that is subject to the EPA Phase II Program would be considered a part of the wasteload allocation, rather than the load allocation. As presented in Chapter IV, V, and VI, of the MEP Technical Report, on Cape Cod the vast majority of stormwater percolates into the aquifer and enters the embayment system through groundwater. Given this, the TMDL accounts for stormwater loadings and groundwater loadings in one aggregate allocation as a non-point source, thus combining the assessments of wastewater and storm water for the purpose of developing control strategies. Ultimately, when the Phase II Program is implemented in Mashpee, Barnstable, and Sandwich, new studies, and possibly further modeling, will identify what portion of the stormwater load may be controllable through the application of BMPs.

The four WWTFs currently discharge about 0.62 kg N/day into the groundwater. This represents less than 1% of the nitrogen load into the Popponesset Embayment System (rounded off to 1% in Figure 4 below). This small percentage of N load is due to the fact that the amount of wastewater effluent discharged by these facilities is small and also that the groundwater discharge permits for three of the four facilities has such a low nitrogen limit that the facilities must use treatment technology

which will denitrify the effluent prior to discharge. Due to the fact that groundwater discharge permits must be renewed over time the fourth wastewater treatment facility will come under the same treatment technology requirements in the near future. If towns shifted loads from on-site systems that do not denitrify (septic systems do not normally denitrify) to these wastewater treatment facilities, it would lead to overall decline in N loadings to the sub-embayments.

The solid waste disposal (landfill) load was included based on data collected from the observation wells. Capping the landfill has eliminated the source of this load, thus the load itself will continue to decrease over time.

The sediment loading rates incorporated into the TMDL are lower than the existing sediment flux rates listed in Table 3 above because projected reductions of N loadings from the watershed will result in reductions of nutrient concentrations in the sediments, and therefore, over time, reductions in loadings from the sediments will occur. Benthic N flux is a function of N loading and particulate organic nitrogen (PON). Projected benthic fluxes are based upon projected PON concentrations and watershed N loads, and are calculated by multiplying the present N flux by the ratio of projected PON to present PON, using the following formulae:

$$\text{Projected N flux} = (\text{present N flux}) (\text{PON projected} / \text{PON present})$$

When:

$$\text{PON projected} = (R_{\text{load}}) (D_{\text{PON}}) + \text{PON}_{\text{present offshore}}$$

$$\text{When } R_{\text{load}} = (\text{projected N load}) / (\text{Present N load})$$

And D_{PON} is the PON concentration above background determined by:

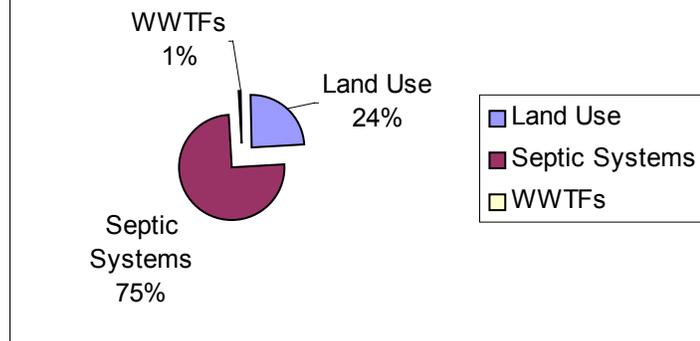
$$D_{\text{PON}} = (\text{PON}_{\text{present embayment}} - \text{PON}_{\text{present offshore}})$$

The benthic flux modeled for the Popponesset Bay System is reduced from existing conditions based on the load reduction and the observed PON concentrations within each sub-embayment relative to Nantucket Sound (boundary condition). The benthic flux input to each sub-embayment was reduced (toward zero) based on the reduction of N in the watershed load.

The loadings from atmospheric sources incorporated into the TMDL, however, are the same rates presently occurring, because, as discussed above, local control of atmospheric loadings is not considered feasible.

Locally controllable sources of N within the watersheds are categorized as on-site subsurface wastewater disposal system wastes, land use (which includes stormwater runoff and fertilizers), and wastewater treatment facilities. The following figure emphasizes the fact that the overwhelming majority of locally controllable N comes from on-site subsurface wastewater disposal systems.

Figure 4
Percent Contribution of Locally Controllable Sources of Nitrogen



Margin of Safety

Statutes and regulations require that a TMDL include a margin of safety (MOS) to account for any lack of knowledge concerning the relationship between load and wasteload allocations and water quality [CWA para 303 (d)(20©, 40C.G.R. para 130.7©(1)]. The EPA's 1991 TMDL Guidance explains that the MOS may be implicit, i.e., incorporated into the TMDL through conservative assumptions in the analysis, or explicit, i.e., expressed in the TMDL as loadings set aside for the MOS. The MOS for the Popponeset Bay System TMDL is implicit, and the conservative assumptions in the analyses that account for the MOS are described below.

1. Use of conservative data in the Linked Model

In the Popponeset Bay System embayments most of the current N load passes through surface water features, which reduce N concentrations. The load model uses attenuation factors for ground water passing through surface water features that are lower than those actually measured. Attenuation factors of 50% are used in the model when measured factors are in the vicinity of 70%. For the TMDL, a smaller than expected attenuation factor makes the allowable loading lower than it would otherwise be and constitutes a portion of the factor of safety.

In addition, using sub-embayments that are at, or near, the inland-most tidal reaches as sentinels for establishing the acceptable nitrogen load (i.e., the TMDL) provides a major margin of safety for "downstream" embayments, which are closer to the mouths. Finally, decreases in air deposition through continuing air pollution control efforts, are uncounted in this TMDL, and are thus another component of the margin of safety.

The hydrodynamic and water quality models have been assessed directly. In the many instances where the hydrodynamic model predictions of volumetric exchange (flushing) have also been directly measured by field measurements of instantaneous discharge, the agreement between modeled and observed values has been $\geq 95\%$. Field measurement of instantaneous discharge was performed using acoustic Doppler current profilers (ADCP) at key locations within the embayment (with regards to the water quality model, it was possible to conduct a quantitative assessment of the model results as fitted to a baseline dataset - a least squares fit of the modeled versus observed data showed an $R^2 > 0.95$, indicating that the model accounted for 95% of the variation in the field data). Since the water quality model incorporates all of the outputs from the other models, this excellent fit indicates a high degree of certainty in the final result. The high level of accuracy of the model provides a high

degree of confidence in the output, therefore, less of a margin of safety is required.

Similarly, the water column N validation dataset was also conservative. The Linked Model is validated to measured water column N. However, the model predicts average summer N concentrations. The very high or low measurements are marked as outliers. The effect is to make the N threshold more accurate and scientifically defensible. If a single measurement 2 times higher than the next highest data point in the series, raises the average 0.05 mg N/L, this would allow for a higher “acceptable” load to the embayment. Marking the very high outlier is a way of preventing a single and rare bloom event from changing the N threshold for a system. This effectively strengthens the data set so that a higher margin of safety is not required.

Finally, it is important to note that the reductions in benthic regeneration of N are most likely underestimates, i.e. conservative. The reduction is based solely on a reduced deposition of PON, due to lower primary production rates under the reduced N loading in these systems. As the N loading decreases and organic inputs are reduced, it is likely that rates of coupled remineralization-nitrification-denitrification and sediment oxidation will increase.

Benthic regeneration of N is dependant upon the amount of PON deposited to the sediments and the percentage that is regenerated to the water column versus denitrified or buried. The regeneration rate projected under reduced N loading conditions was based upon two assumptions:

- a) the PON in the embayment in excess of that of inflowing tidal water (boundary condition) results from production supported by watershed N inputs and
- b) the presently enhanced production would decrease in proportion to the reduction in the sum of watershed N inputs + plus direct atmospheric N input. The latter condition would result in equal embayment versus boundary condition production and PON levels if watershed N loading + direct atmospheric deposition could be reduced to zero (an impossibility of course).

This proportional reduction assumes that the proportion of remineralized N will be the same as under present conditions, which is almost certainly an underestimate. As a result future N regeneration rates are overestimated, which adds to the margin of safety.

2. Conservative threshold sites/nitrogen concentrations

Conservatism was used in the selection of the threshold sites and N concentration. Sites were chosen that had benthic animal (infaunal) communities, and not those just starting to show impairment, which would have slightly higher N concentrations. Meeting the target thresholds in the sentinel sub-embayments will result in reductions of N concentrations in the rest of the systems, which is very conservative, thus adding to the margin of safety for those embayments as a whole.

In addition to the margin of safety within the context of setting the N threshold levels, described above, a programmatic margin of safety also derives from continued monitoring of these sub-embayments to support adaptive management. This continuous monitoring effort provides the ongoing data to evaluate the improvements that occur over the multi-year implementation of the N management plan. This will allow refinements to the plan to ensure that the desired level of restoration is achieved.

Seasonal Variation

Nutrient loads to the sub-embayments are based on annual loads for two reasons. Since the TMDLs for the waterbody segments are based on the most critical time period, i.e. the summer growing season, the TMDLs are protective for all seasons. The daily loads can be converted to annual loads by multiplying by 365 (the number of days in a year). Nutrient loads to the sub-embayments are based on annual loads for two reasons. The first is that primary production in coastal waters can peak in both the late winter-early spring and in the late summer-early fall periods. Second, as a practical matter, the types of controls necessary to control the N load, the nutrient of primary concern, by their very nature do not lend themselves to intra-annual manipulation since the majority of the N is from non-point sources. Thus, the annual loads make sense, since it is difficult to control non-point sources of nitrogen on a seasonal basis and that nitrogen sources can take considerable time to migrate to impacted waters.

TMDL Values for Popponesset Bay Sub-Embaysments

As outlined above, the total maximum daily loadings of N that would provide for the restoration and protection of each sub-embayment, were calculated by considering all sources of N grouped by natural background, point sources, and non-point sources. A more meaningful way of presenting the loadings data, from an implementation perspective, is presented in Table 5. In this table the N loadings from the atmosphere and nutrient-rich sediments are listed separately from the target watershed threshold loads, which are composed of natural background N along with locally controllable N from the WWTP, on-site subsurface wastewater disposal systems, stormwater runoff, and fertilizers. In the case of Popponesset Bay, the TMDLs were calculated by projecting reductions in locally controllable on-site subsurface wastewater disposal system, stormwater runoff, and fertilizer sources.

Table 5. The Total Maximum Daily Loads (TMDL) for the Popponesset Bay System, represented as the sum of the calculated target thresholds loads (from controllable watershed sources), atmospheric deposition, and sediment sources (benthic flux).

Popponesset System Sub-embayment	Target Watershed Threshold Load ¹ (kg/day)	Atmospheric Deposition (kg/day)	Benthic Flux ² (kg/day)	TMDL ³ (kg/day)
Mashpee River	16.2	0.7	9.4	26
Shoestring Bay	19.7	2.2	-8.7	13
Ockway Bay	0.8	1.1	1.1	3
Pinquickset Cove	0.8	0.3	-0.3	1
Popponesset Bay	2.8	4.0	-5.5	1

¹ Target threshold watershed load is the load from the watershed needed to meet the embayment threshold concentrations identified in Table 2. Once again the goal of this TMDL is to achieve the identified N threshold concentration in the identified sentinel system. The target load identified in this table represents one alternative loading scenario to achieve that goal but other scenarios may be possible and approvable as well.

² Projected sediment N loadings obtained by reducing the present loading rates (Table 3) proportional to proposed watershed load reductions and factoring in the existing and projected future concentrations of PON.

³ Sum of target threshold watershed load, atmospheric deposition load, and benthic flux load.

Implementation Plans

The critical element of this TMDL process is achieving the sub-embayment specific N concentrations presented in Table 2 above, that are necessary for the restoration and protection of water quality and eelgrass habitat within the Popponneset Bay sub-embayments. In order to achieve those target concentrations, N loading rates must be reduced throughout the Popponneset Bay System. Table 5, above, lists target watershed threshold loads for each sub-embayment. If those threshold loads are achieved, the overall Popponneset Bay System will be protected.

This loading reduction scenario is not the only way to achieve the target N concentrations. The Towns are free to explore other loading reduction scenarios through additional modeling as part of the Comprehensive Wastewater Management Plan (CWMP). It must be demonstrated, however, that any alternative implementation strategies will be protective of the overall Popponneset Bay System, and that none of the sub-embayments will be negatively impacted. To this end, additional linked model runs can be performed by the MEP at a nominal cost to assist the planning efforts of the Towns in achieving target N loads that will result in the desired threshold concentrations.

The CWMP should include a schedule of the selected strategies and estimated timelines for achieving those targets. However, the DEP realizes that an adaptive management approach may be used to observe implementation results over time and allow for adjustments based on those results.

Because the vast majority of controllable N load is from individual on-site subsurface wastewater disposal systems for private residences, the CWMP should assess the most cost-effective options for achieving the target N watershed loads, including but not limited to, sewerage and treatment for N control of sewage and septage at either centralized or de-centralized locations, and denitrifying wastewater treatment systems for private residences.

The Towns, however, are urged to meet the target threshold N concentrations by reducing N loadings from any and all sources, through whatever means are available and practical, including reductions in stormwater runoff and/or fertilizer use within the watershed through the establishment of local by-laws and/or the implementation of stormwater BMPs, in addition to reductions in on-site subsurface wastewater disposal system loadings.

Although it is not explained in detail previously in this TMDL, it should be noted here that parts of the Town of Sandwich are in the watershed of the Popponneset Bay System. A portion of the upper Mashpee River sub-embayment watershed is located in Sandwich. Thus the development of any implementation plan should keep in mind that a third town needs to be included in coordinating efforts to maximize the reduction in TN loading.

DEP's MEP Implementation Guidance report (<http://www.mass.gov/dep/water/resources/restore.htm>) provides N loading reduction strategies that are available to the Towns of Mashpee, Barnstable and Sandwich and that could be incorporated into the implementation plans. The following topics related to N reduction are discussed in the Guidance:

- Wastewater Treatment
 - On-Site Treatment and Disposal Systems
 - Cluster Systems with Enhanced Treatment
 - Community Treatment Plants
 - Municipal Treatment Plants and Sewers
- Tidal Flushing

- Channel Dredging
 - Inlet Alteration
 - Culvert Design and Improvements
- Stormwater Control and Treatment *
 - Source Control and Pollution Prevention
 - Stormwater Treatment
- Attenuation via Wetlands and Ponds
- Water Conservation and Water Reuse
- Management Districts
- Land Use Planning and Controls
 - Smart Growth
 - Open Space Acquisition
 - Zoning and Related Tools
- Nutrient Trading

* The Towns of Mashpee, Barnstable and Sandwich are three of 237 communities in Massachusetts covered by the Phase II stormwater program requirements.

Monitoring Plan for TMDL Developed Under the Phased Approach

The Department recommends that the Towns of Mashpee and Barnstable develop a detailed monitoring plan as part of the Comprehensive Wastewater Management Planning process and as part of the detailed plan for TMDL implementation. The monitoring plan should be designed to determine to what extent water quality improvements occur as a result of implementing this TMDL, and should be developed and conducted in phases according to the identification of N reduction options. The Department recognizes the long-term nature of the time horizon for full implementation of the TMDL; however, reasonable milestones in the shorter term are necessary.

Growth should be guided by a consideration of water quality-associated impacts.

Reasonable Assurances

DEP possesses the statutory and regulatory authority, under the water quality standards and/or the State Clean Water Act (CWA), to implement and enforce the provisions of the TMDL, including requirements for N loading reductions from on-site subsurface wastewater disposal systems. However, because most non-point source controls are voluntary, reasonable assurance is based on the commitment of the locality involved. Both Mashpee and Barnstable have demonstrated this commitment through the comprehensive wastewater planning that they initiated well before the generation of the TMDL. The Towns expect to use the information in this TMDL to generate support from their citizens to take the necessary steps to remedy existing problems related to N loading from on-site subsurface wastewater disposal systems, stormwater, and runoff (including fertilizers), and to prevent any future degradation of these valuable resources. Moreover, reasonable assurances that the TMDL will be implemented include enforcement of regulations, availability of financial incentives and local, state and federal programs for pollution control. Storm water NPDES permit coverage will address discharges from municipally owned storm water drainage systems. Enforcement of regulations controlling non-point discharges include local implementation of the Commonwealth's Wetlands Protection Act and Rivers Protection Act; Title 5 regulations for on-site subsurface wastewater disposal systems, and other local regulations such as the Town of Rehoboth's stable regulations. Financial incentives include federal funds available under Sections 319, 604 and 104(b) programs of the CWA, which are provided as part of the Performance Partnership Agreement

between MA DEP and EPA. Other potential funds and assistance are available through Massachusetts' Department of Agriculture's Enhancement Program and the United States Department of Agriculture's Natural Resources Conservation Services. Additional financial incentives include income tax credits for Title 5 upgrades and low interest loans for Title 5 on-site subsurface wastewater disposal system upgrades available through municipalities participating in this portion of the state revolving fund program.

Appendix A

Table A – 1: Summarizes the nitrogen concentrations for Popponeset Bay sub-embayments (from Chapter VI of the accompanying MEP Technical Report, Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for Popponeset Bay, Mashpee and Barnstable, Massachusetts, July

Table VI-1. Measured and modeled Nitrogen concentrations for the Popponeset Bay system used in the model calibration plots of Figure VI-2. All concentrations are given in mg/L N. "Data mean" values are calculated as the average of the separate yearly means. Overall mean is presented as "data mean" with the standard deviation (s.d.) and number of total samples (N).														
Sub-Embayment	monitoring station	1997 mean	1998 mean	1999 mean	2000 mean	2001 mean	2002 mean	2003 mean	data mean	s.d. all data	N	model min	model max	Model avg
Mashpee River - head (MRh)	PB 1	0.798	0.633	0.787	0.831	0.990	1.137	0.756	0.859	0.200	26	0.786	0.952	0.851
Mashpee River - Upper (MRu)	PB2	1.006	0.726	1.022	0.798	1.082	1.153	0.892	0.958	0.242	24	0.862	1.016	0.932
Mashpee River - Mid (MRm)	PB3	0.651	0.764	0.669	0.596	0.740	1.120	0.733	0.739	0.216	25	0.530	1.009	0.837
Mashpee River - Lower (MRI)	PB4	0.603	0.668	0.564	0.485	0.695	0.694	0.736	0.627	0.134	25	0.346	0.955	0.588
Shoestring Bay - head (SBh)	SR 5	-	1.193	0.860	0.878	1.278	1.132	1.377	1.135	0.380	20	0.965	1.166	1.071
Shoestring Bay - upper (SBu)	PB5	0.730	0.878	0.606	0.594	0.678	0.580	0.870	0.690	0.169	26	0.663	0.772	0.711
Shoestring Bay - mid (SBm)	PB 6	0.617	0.695	0.644	0.671	0.668	0.707	0.884	0.688	0.140	28	0.514	0.732	0.640
Shoestring Bay - lower (SBl)	PB 7	0.518	0.551	0.467	0.506	0.507	0.527	0.592	0.520	0.113	27	0.386	0.690	0.541
Ockway Bay - upper (OBu)	PB 9	0.552	0.569	0.498	0.486	1.003	0.785	0.734	0.677	0.217	27	0.552	0.586	0.567
Ockway Bay - lower (OBl)	PB 10	0.485	0.508	0.426	0.467	0.765	0.592	0.512	0.536	0.177	27	0.331	0.575	0.476
Popponeset Bay – head (PBh)	PB 8	0.476	0.589	0.444	0.592	0.772	0.595	0.732	0.581	0.151	24	0.307	0.694	0.464
Popponeset Bay – upper (PBu)	PB 11	0.307	0.521	0.434	0.417	0.579	0.567	0.506	0.485	0.111	23	0.290	0.552	0.381
Popponeset Bay - mid (PBm)	PB 12	0.343	0.492	0.393	0.473	0.539	0.554	0.486	0.456	0.102	25	0.282	0.501	0.328
Popponeset Creek (POC)	PB 13	0.369	0.376	0.351	0.486	0.591	0.456	0.479	0.422	0.107	23	0.359	0.381	0.370
Pinquicket Cove (PQC)	PB 15	-	-	-	-	-	0.470	0.640	0.527	0.097	6	0.335	0.460	0.416
Nantucket Sound (NAS)	PB 14	0.260	0.282	0.297	0.326	0.368	0.351	0.375	0.315	0.055	22	0.283	0.323	0.288

Appendix B

Table B –1 Summarizes the present on-site subsurface wastewater disposal system loads, and the loading reductions that would be necessary to achieve the TMDL by reducing on-site subsurface wastewater disposal system loads, ignoring all other sources.

Table VIII-1. Comparison of sub-embayment watershed septic loads (attenuated) used for modeling of present and threshold loading scenarios of the Popponeset Bay system. These loads do not include direct atmospheric deposition (onto the sub-embayment surface), benthic flux, runoff, or fertilizer loading terms.			
sub-embayment	present septic load (kg/day)	threshold septic load (kg/day)	threshold septic load % change
Popponeset Bay	1.58	1.58	0.0%
Popponeset Creek	4.00	0.00	-100.0%
Pinquisset Cove	0.58	0.58	0.0%
Ockway Bay	2.39	0.00	-100.0%
Mashpee River	9.61	0.00	-100.0%
Shoestring Bay	6.94	0.00	-100.0%
Surface Water Sources			
Mashpee River	9.96	5.85	-41.3%
Santuit River (Shoestring Bay)	11.69	7.58	-35.2%
Quaker Run River (Shoestring Bay)	4.69	4.69	0.0%
TOTAL	51.12	19.96	-61.0%

Appendix C

Popponeset Bay Embayment System estimated wasteload allocation (WLA) from runoff of all impervious areas within 200 feet of waterbodies.

Subwatershed Name	Impervious subwatershed buffer areas ¹		Total Subwatershed Impervious areas		Total Impervious subwatershed load	Total subwatershed load	Impervious subwatershed buffer area WLA	
	Acres	%	Acres	%	Kg/year	Kg/year	Kg/year	%
Mashpee River	5.5	5.3	643.5	8.6	1411	13010	12.06	0.09
Shoestring Bay	10	12.4	426	10.1	986	13012	23.15	0.18
Ockway Bay	5.8	6.0	27.6	11.7	90	1549	18.91	1.22
Pinquisset Cove	0.9	3.6	8.4	4.2	10	385	1.07	0.28
Popponeset Bay	14.4	6.6	50.2	25	170	3929	62.31	1.59
TOTAL	40.6	9.8	1155.7	9.5	2667	31885	93.69	0.29

¹The entire impervious area within a 200 foot buffer zone around all waterbodies as calculated from GIS. Due to the soils and geology of Cape Cod it is unlikely that runoff would be channeled as a point source directly to a waterbody from areas more than 200 feet away. Some impervious areas within approximately 200 of the shoreline may discharge stormwater via pipes directly to the waterbody. For the purposes of the wasteload allocation it was assumed that all impervious surfaces within 200ft of the shoreline discharge directly to the waterbody.